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Physiological effects of potassium and growth regulators in pigeon pea [*Cajanus cajan* (L.) Millsp.]

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Abstract
Low yields and indeterminate growth in pigeon pea [*Cajanus cajan* (L.) Millsp.], have been causes of concern which calls for scientific investigations on management techniques to regulate the source–sink balance for enhancing productivity. The experiment with combinations of different sources and concentrations of K, and three growth regulators as treatments and a control with no foliar application was laid out in RBD with three replications. Foliar application of KNO_3 and gibberellic acid significantly improved leaf area index, crop growth rate, yield and nutrient uptake. Brassinosteroid could induce earliness in flowering, but the favorable effect was not reflected in the fertility coefficient and yields. Seed yield (1186.33 kg ha^{-1}), and soluble protein (60.70 mg kg^{-1}) were the highest in KNO_3 (0.5%) x GA_3 (75 mg kg^{-1}) application. Potassium K sources and growth regulators were effective in emulating superior physiological effects in pigeon pea that eventuated in better seed yields.

Keywords: CGR, foliar, gibberellic acid, potassium, soluble protein

1. Introduction

Pigeon pea [*Cajanus cajan* (L.) Millsp.] Being nutrient rich and adaptable to dry climate, is considered a key crop for food and nutritional security. Kerala, the southernmost state in India is known for its wealthy agricultural heritage and unique diversified farming systems. Grain legumes are important components of the cropping systems in the state, nevertheless, are limited to cowpea, green gram and black gram. Pigeon pea, also called red gram, despite being an integral ingredient in the daily cuisines of the people, has not evolved as a major pulse crop for cultivation. The indeterminate growth habit, poor pod set, grain filling, low yield and lack of post-harvest management facilities are some of the constraints that has affected its cultivation. Hence, despite its ecological benefits, the cultivation is often rendered to be less profitable. Ergo, it has become imperative to adopt suitable management practices and manipulate the microclimate to ensure proper source- sink balance and yields, in accordance to its genetic potential.

Plant nutrition is of paramount importance in plant growth and development. The availability of nutrients in balanced ratios is crucial for the crop to express its genetic potential in interaction with the environment variables. Growth regulators are known to modify and re-shape crop plants by altering the responses to the different factors that govern development (Kumar *et al*., 2022) [16]. Studies on the response of short duration varieties of pigeon pea to different levels of nutrient doses (Devaraj and Isaac, 2023) [5] revealed 40: 80: 40 kg NPK ha^{-1} to be the most optimum for higher yields. Among the major nutrients, potassium (K) is regarded the soldier safeguarding crops against diseases and inducing drought tolerance. It has the additional role of ensuring adequate translocation of assimilates to the sink from the site of synthesis (Hasanuzzaman *et al*., 2018) [9]. It is hypothesized that proper scheduling of K application, extending to the flowering stages, can impact shedding and pod development. This coupled with growth regulators can indubitably influence seed yields. Ramteke *et al*. (2022) [23] documented that the application of nutrients, when done through foliage increases the use efficiency and reducing losses as they are targeted directly towards the synthesis of photo-assimilates. Keeping these in view, an investigation was taken up in Kerala Agricultural University to evaluate the effects of foliar nutrition of K with different sources, and growth regulators on the growth rates and biomass partitioning in pigeon pea.

2. Materials and Methods

The field experiment was conducted at College of Agriculture, Vellayani, Thiruvananthapuram, Kerala Agricultural University, during *Rabi* 2021. It was laid out in randomised block design (RBD) with 12 treatments and one control, in three replications. The treatments included 12 combinations of two factors, four levels of K (a_1 - 0.5% K_2SO_4, a_2 - 1.0% K_2SO_4, a_3 - 0.25% KNO_3, a_4 - 0.5% KNO_3) and three growth regulators (b_1– gibberellic acid (GA3) 75 mg kg^{-1}, b_2 - brassinosteroid (BR) 0.1 mg kg^{-1}, b_3 - humic acid (HA) 100 mg kg^{-1}), and were compared with the control raised with recommended dose of nutrients without foliar nutrition. Foliar application was done twice, K- at flower bud and pod formation stages, and growth regulators - 30 days after sowing (DAS) and at flower bud stage.

The Pigeon pea variety APK 1 was used in the study, is a short duration pure line selection from ICPL 87101, with determinate growth habit and matures in 95 to 105 days. Seeds were sown at 40 cm x 20 cm spacing and fertilised at an NPK dose of 40:80:40 kg ha^{-1} using the fertilizers, urea, rajphos and muriate of potash, in soil. Half the dose of N, full P_2O_5 and K_2O were applied basally, and the remaining N was applied at 30 DAS. All other management practices were adopted uniformly in all plots until harvest. Picking of pods was done manually when they turned reddish brown and plants showed shedding of leaves. Seeds were extracted by threshing the pods followed by winnowing, and later weighed to record seed yields.

Leaf area and Leaf area index (LAI)

Leaf area was calculated by measuring the length and breadth of the middle leaflet in the three fully opened leaves at the top, at flowering, and mean was worked out and then multiplied with the constant 0.748 recommended for pigeon pea (Sharma *et al.*, 1987) [28]. The data was used to compute leaf area index using the formula proposed by Watson (1947) [33].

$$\text{LAI} = \frac{\text{Leaf area per plant}}{\text{Land area occupied by the plant}}$$

The observations on dry matter production were recorded at periodic intervals and used to compute the growth rates.

Crop growth rate (CGR)

CGR was calculated between 30-60 DAS, 60-90 DAS and 90 DAS-harvest adopting the formula suggested by Watson (1947) [33].

$$\text{CGR} = \frac{w_2 - w_1}{t_2 - t_1} \times \frac{1}{A}$$

Where,
w_1: Dry weight of plant (g) at time t_1 (days)
w_2: Dry weight of plant (g) at time t_2 (days)
A: Land area (m^2)

Relative leaf water content (RLWC)

RLWC of the sample plants was determined at flowering stage as proposed by Pieczynski *et al.* (2013) [21].

$$\text{RLWC (\%)} = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100$$

Chlorophyll content estimation was done at flowering, as per the procedure described by Arnon (1949) [1]. Dry Matter Partitioning (DMP) was computed from the dry weights recorded on the plant parts, shoot, root and pods per plant and expressed as percentage. The nutrient contents in the different plant parts were analysed following standard procedures and multiplied by the DMP to calculate the nutrient uptake.

Statistical analysis

The data were subjected to analysis of variance (ANOVA) suggested by Panse and Sukhatme (1985) [20] as applied to two factor randomized block design. Control *vs* treatment comparison was done as contrast analysis using GRAPES software developed by the Department of Agricultural Statistics, College of Agriculture, Vellayani. Critical difference was calculated in cases where treatment effects were found to be significant.

3. Results and Discussion

The physiological effects of foliar application of K and growth regulators in pigeon pea are presented in Tables 1 to 3.

3.1 Effects of foliar application of K and growth regulators in redgram on LAI

The data furnished in Tables 1 and 2 revealed the significant influence of K sources at different concentrations on LAI in pigeon pea. The highest LAI (2.08) was recorded in a_4 (0.5% KNO_3) and the lowest (1.79) in a_2 (1.0% K_2SO_4). Among growth regulators, LAI (2.59) was maximum in b_1 (GA_3). It was significantly superior to BR and humic acid application. Interactions could not exhibit any significant effect on LAI. However, the treatments were found to be significantly superior to the control.

Leaf area index measured as the total leaf area per square metre of ground area, is an index of leafiness of the plant. Leaves are the sites of photosynthesis and defines the source strength. The higher LAI in a_4 and b_1 implied efficient photosynthesis in response to the foliar nutrition. Among the treatments of K, the 0.5% KNO_3 (a_4) had the additional advantage of K and N in the same source, and at higher concentrations compared to KNO_3 in a_3 (0.25%). Similar reports have been documented by Govindan and Thirumurugan (2000) [8] in green gram. Although the beneficial effects of humic acid and brassinolide in improving plant growth have been reported earlier (Mawgoud *et al.*, 2007; Sengupta *et al.*, 2011) [17;26], it was not pronounced in the present study. Gibberellic acid excelled among the growth regulators. The maximum LAI noted with GA_3 application is consequent to the effect of the growth regulator in fostering cell division and expansion, resulting in higher leaf area. Better leaf growth boosted the photosynthetic rate within the canopy by absorbing maximum sunlight (Khan, 1996) [14]. The treatment effects were plainly evident and showed superiority over no application.

Table 1: Effect of K and growth regulators on LAI, CGR and soluble protein in leaves

Treatments	LAI	CGR ($g\ m^{-2}\ day^{-1}$)			Soluble protein ($mg\ mL^{-1}$)
		30-60 DAS	60-90 DAS	90 DAS -Harvest	
K (a)					
a_1 (0.5% K_2SO_4)	1.81	4.94	9.52	3.16	52.77
a_2 (1.0% K_2SO_4)	1.79	5.12	9.12	2.76	48.96
a_3 (0.25% KNO_3)	1.89	5.35	9.22	3.22	48.41
a_4 (0.5% KNO_3)	2.08	5.88	9.67	3.45	53.64
SE m (±)	0.05	0.13	0.04	0.03	0.38
CD (0.05)	0.156	0.363	0.096	0.084	1.141
Growth regulators (b)					
b_1 (GA_3 75 mg kg^{-1})	2.59	6.14	11.21	2.51	57.29
b_2 (BR 0.1 mg kg^{-1})	1.62	5.76	9.65	2.28	49.46
b_3 (HA 100 mg kg^{-1})	1.47	4.87	8.66	2.13	46.08
SE m (±)	0.05	0.28	0.18	0.05	0.33
CD (0.05)	0.135	0.828	0.523	0.139	0.988

3.2 Effects of K, growth regulators and interactions on CGR

The effect of K, growth regulators and their interactions on CGR at 30-60, 60-90 DAS and 90 DAS-harvest are presented in Tables 1 and 2. Crop growth rate was maximum at 60-90 DAS irrespective of the treatments coinciding with its grand growth phase. At all periods of observation, individual effects of the treatments revealed the significantly highest CGR in a_4 (0.5% KNO_3) and b_1 (GA_3) Consequently, among interactions a_4b_1 surpassed all other combinations with better CGR (6.12, 11.45 and 3.41 $gm^{-2}day^{-1}$ at the three stages respectively), and the lowest was recorded in a_1b_3 at 30-60 DAS whereas at 60-90 DAS and 90 DAS-harvest, it was in a_2b_3. The treatment effects were also superior to the control.

Crop growth rate (CGR) portrays the biomass production per unit land area per unit time, the product of incoming solar radiation intercepted by the crop as decided by LAI. In growth and development, it is annotated as the efficiency with which the intercepted radiation is used to produce biomass. The values in pigeon pea, irrespective of the treatments were found to increase as growth progressed and was maximum during 60- 90 DAS and thereafter, declined. The increase in the early stages can be inferred as the response to the management practices including foliar application and the variations due to treatment effects. Drying and leaf shedding during maturity and senescence were responsible for the decline at later stages. The CGR at different crop growth stages and the trend over the crop duration revealed maximum values in the treatment involving KNO_3 application at 5% concentration. This is attributed to the interactive effect of K and N in the applied KNO_3 on biomass production. Cakmak (2005) [4] reported that N interacts with phyto-hormones, effectually increasing growth, photosynthesis and carbohydrate accumulation The increased growth rate with GA_3 might be due its conducive influence on growth by stimulating cell elongation which enhanced leaf area, ensuring effective photosynthesis and carbohydrate accumulation. According to Khan *et al*. (2007) [13], gibberellic acid improves photosynthetic efficiency of plants through the influence on photosynthetic enzymes, LAI, light interception and enhanced nutrient use efficiency. Brassinosteroid and HA also enhanced the growth rates in comparison to no application. The interactive effect of KNO_3 and GA on CGR values at all stages of growth is surmised as the cumulative effect of the treatments.

Table 2: Interaction effect of K and growth regulators on LAI, CGR and soluble protein in leaves

Treatments	LAI	CGR ($g\ m^{-2}\ day^{-1}$)			Soluble protein ($mg\ mL^{-1}$)
		30-60 DAS	60-90 DAS	90 DAS-Harvest	
a_1b_1	2.48	5.45	10.53	3.21	58.54
a_1b_2	1.53	4.98	9.34	2.76	52.39
a_1b_3	1.43	4.61	8.76	2.21	47.38
a_2b_1	2.35	5.66	9.87	3.21	55.14
a_2b_2	1.61	4.65	9.46	2.36	48.34
a_2b_3	1.41	5.43	8.65	1.92	43.41
a_3b_1	2.68	5.61	10.33	3.12	54.77
a_3b_2	1.51	5.13	9.44	2.99	43.86
a_3b_3	1.47	4.87	8.99	2.13	46.59
a_4b_1	2.84	6.12	11.45	3.51	60.70
a_4b_2	1.82	5.78	10.43	2.35	53.25
a_4b_3	1.58	4.76	9.45	2.12	46.96
SE m (±)	0.09	0.20	0.31	0.18	0.67
CD (0.05)	NS	0.586	0.905	0.496	1.976
Control (C)					
C (RDF alone)	1.34	4.45	8.32	1.71	37.58
Treatment *vs* Control	S	S	S	S	S

3.3 Effects of K, growth regulators and interaction on dry matter partitioning

Statistical comparison of dry matter partitioning to the different plant parts in response to foliar nutrition are depicted in Tables 3 and Fig.1. It was evident that the dry matter allocation to the shoots (37.40 to 45.80%) was almost similar to that in the pods (31.99 to 45.06%). Roots accounted for the lowest accumulation.

Biomass accumulation in shoots was maximum in 0.25% KNO_3 comparable with a_1 and a_2 but, significantly superior to a_4. In pods, it was significantly the highest in KNO_3 @ 0.5% (41.55%) and the lowest, (36.71%) in a_3 (0.25% KNO_3). Root dry weights remained the highest when K_2SO_4 was applied at 1.0% concentration (20.12%) on par with K_2SO_4 at 0.5 and KNO_3 at 0.25% concentrations. This varied response was noticed with the growth regulators too. The effects were comparable in shoot biomass, while in pods, b_1 was superior and in roots, humic acid (b_3) produced maximum accumulation. Among the treatment combinations, a_3b_2 recorded higher accumulation in shoot and roots and remained comparable for pods. However, the treatments were superior to the control. The distribution of dry matter among the plant parts is one of the crucial variables that affects the survival, competitive ability and performance of a single plant. The partitioning is indicative of the source- sink relationship in the plant. Dry matter partitioning at harvest in pigeon pea revealed accumulation to follow the order shoots > pods > roots in general, whereas it was almost similar in shoots and pods in KNO_3 application at 0.5% concentration. However, comparing the partitioning in a x b interactions, the dry matter accumulation in pods was comparatively greater than that in the shoots, and nearly 21.04% higher than that in the control with no foliar application. This brings to focus the significant influence of K and growth regulators in enhancing the pod yields.

Table 3: Effect of K and growth regulators on dry matter partitioning in pigeon pea at harvest (%)

Treatments	Dry matter partitioning		
	Shoots	Pods	Roots
K (a)			
a_1 (0.5% K_2SO_4)	42.74	37.89	19.36
a_2 (1.0% K_2SO_4)	42.38	37.50	20.12
a_3 (0.25% KNO_3)	43.98	36.71	19.31
a_4 (0.5% KNO_3)	41.10	41.55	17.36
SE m (±)	0.55	0.68	0.42
CD (0.05)	1.616	2.012	1.310
Growth regulators (b)			
b_1 (GA_3 75 mg kg^{-1})	41.82	41.46	17.14
b_2 (BR 0.1 mg kg^{-1})	42.46	40.38	17.15
b_3 (HA 100 mg kg^{-1})	42.59	35.03	22.41
SE m (±)	0.47	0.59	0.43
CD (0.05)	NS	1.743	1.256

A balanced supply to the shoots and pods (37-44%) in the treatments unlike that in the control (> 52% to shoots) stipulates the modulation of the source strength and sink capacity in favour of productivity. It is deduced that the role of K and GA_3 in phloem uploading and translocation, as enumerated by Gajdanowicz *et al*. (2011) [6] and Solaimalai *et al.* (2001) [30], would have contributed to the better accumulation in pods (45.06%). Nitrogen positively influences the greenness of leaves and leaf area ensuing higher photosynthetic efficiency in the plants. Gibberellic acid is known to mediate photosynthesis, sucrose synthesis, assimilate translocation (Iqbal *et al*., 2011) [11] and thus regulate source- sink relations, as elucidated in pigeon pea (Kumar and Sharma, 2021) [15]

3.4 Effect of Growth regulator and treatment combinations on days to flowering

Variations in the number of days taken to attain 50% flowering in pigeon pea due to K, growth regulators and their interactions (Tables 4 and 5) showed that the growth regulator, BR 0.1 mg kg^{-1} could induce earliness in flowering (57.6 days), whereas it was found delayed the maximum (66.3 days) in humic acid applied plants. Among the treatment combinations a_1b_2 (0.5% K_2SO_4 + BR 0.1 mg kg^{-1}) recorded earliness in flowering (57.2 days) while it was impeded in a_4b_3 (0.5% KNO_3 + HA). Foliar application of nutrients during flower and grain formation stages implicated efficient utilisation of nutrients thereby reducing flower shedding and enhancing yields (Sathishkumar *et al*., 2020; Singh *et al*., 2021) [25;29]. Application of BR induces pollen tube growth and germination, which incites earliness in flowering (Hewitt *et al.* 1985)[10]. Sairam (1994) [24] stated that application of BR increases the nitrate reductase activity which is an essential enzyme for flowering, and this might have contributed to the early flower induction in b_2. Similar observations were documented by Senthil *et al.* (2003) [27] in soybean and Rajavel (2004) [22] in black gram. The treatments were significantly superior, the mean number of days taken was lower than that in control (69.1 days). This proves the efficacy of foliar K and growth regulators in hastening flowering which would otherwise have been delayed under normal package recommendations.

3.5 Effects of K, growth regulators and interaction on fertility co-efficient

Fertility coefficient computed varied significantly with the treatments (Tables 4 and 5). Perusal of the individual effects revealed a_4 (0.5% KNO_3) and b_1 (GA_3) to record the highest fertility co-efficient and its combination a_4b_1, also evoked significantly superior value (34.11%). The treatment effects were significantly superior to control. In comparison to GA_3, BR actuated earliness in flowering. However, this was not reflected in the yields. On analysis of the data it was evident that despite an early initiation in flowering, the percentage pod set as depicted by the fertility coefficient (27.57%), was significantly lower in BR treatment and these eventuated in lower pod number and yields compared to GA application. Flower and fruit drop are the major physiological constraints in pigeon pea cultivation. As per the results of the present study, GA was found to be superior in lowering flower abscission thus contributing to the higher yields in the treatment.

3.6 Effects of K, growth regulators and interaction seed yield

Individual effect of the treatments revealed that the seed yields were significantly higher in a_4 (0.5% KNO_3) and b_1 (GA_3 75 mg kg^{-1}), the values being 1081.33 and 1100.13 kg ha^{-1} respectively (Table 3a). Interactions also showed significant variations in the seed yield (Table 5) with a_4b_1 recording superior yields (1186.33 kg ha^{-1}). The yield computed as mean of treatments was 29.41% higher in a_4b_1, establishing the influential role of foliar nutrition in growth and yield enhancement in pigeon pea. The higher yields realized with KNO_3 at 0.5% and growth regulator GA_3 individually and in the interaction are the manifestation of the positive effects the treatments had on the growth rates, leaf area and partitioning of assimilates to the sink, unlike when nutrient management is confined to soil application. Foliar application has the advantages of ease in nutrient accessibility and increased quantum of availability, especially at flowering which rejuvenated the plants to be physiologically more active to build up sufficient food reserves for the developing flowers and seeds. This subsequently ensured continued translocation of photosynthates, which eventually enhanced yields.

Table 4: Effect of K and growth regulators on seed yield and nutrient uptake

Treatments	Days to 50% flowering	Fertility co-efficient (%)	Seed yield (kg ha^{-1})	Nutrient uptake (kg ha^{-1})		
				N	P	K
K (a)						
a_1 (0.5% K_2SO_4)	61.8	25.00	1040.41	105.85	24.87	43.79
a_2 (1.0% K_2SO_4)	62.3	24.18	1006.13	108.35	29.12	42.54
a_3 (0.25% KNO_3)	62.4	25.73	1014.44	112.67	27.92	47.23
a_4 (0.5% KNO_3)	61.9	28.95	1081.33	122.40	31.23	49.98
SE m (±)	0.19	0.43	5.02	0.70	0.32	0.67
CD (0.05)	NS	1.280	14.804	2.084	0.966	1.976
Growth regulators (b)						
b_1 (GA_3 75 mg kg^{-1})	62.4	28.77	1100.13	113.30	29.60	43.56
b_2 (BR 0.1 mg kg^{-1})	57.6	27.57	1072.74	109.65	27.78	42.19
b_3 (HA 100 mg kg^{-1})	66.3	21.56	934.02	112.41	26.74	39.98
SE m (±)	0.17	0.38	4.34	0.61	0.10	0.11
CD (0.05)	0.499	1.109	12.821	NS	0.317	0.324

3.7 Effects of K, growth regulators and interaction nutrient uptake: Foliar nutrition of K exerted significant influence on the nutrient uptake (N, P and K) in pigeon pea at harvest. (Table 4). Among the various sources of K at varying level of concentrations, the application of KNO_3 at 0.5% recorded the significantly superior uptake of the nutrients, N, P and K. The effect of growth regulators on the uptake of N was non-significant, but were marked for P and K with GA_3 indicating maximum uptake. The interaction effect of K and growth regulators was significantly the highest in a_4b_1 (0.5% KNO_3 x GA_3). The control recorded the lowest nutrient uptake in comparison to the other treatment combinations. The higher nutrient uptake with the KNO_3 @ 0.5% application may be attributed to increased absorption of the foliar applied K and N, which favoured efficient partitioning to the pods thus adding to the total dry matter production. It also needs to be mentioned that the legume effect of pigeon pea (Ghosh *et al.,* 2007) [7] augmented P solubilization and uptake by the crop which also contributed to the higher P uptake values. Tiwari *et al*. (2012) [32] documented enhanced uptake of N with improved supply of K and increased assimilation of K with the higher K levels (Balpande *et al*., 2016) [2] while a balanced and enhanced uptake of N, P and K with K application has been elucidated (Jiku Md *et al*., 2020) [12].

The highest uptake values recorded with application of GA_3 (Table 4) might be due to the enhanced nutrient use efficiency (Yamaguchi, 2008) [35]. Application of GA_3 ensures efficient uptake of plant nutrients by increasing their mobility, leading to better source-sink relationship (Mousa *et al.,* 2001) [19]. The percent increase in the nutrient uptake of N, P, and K in the treatment effects over the control (no foliar spray) was 16.23, 20.63, and 38.05% respectively. The superiority noted is attributed to the higher availability and better absorption of nutrients through foliage and the growth promoting effects of the growth regulators that enhanced the yield attributes and dry matter production.

Table 5: Interaction effect of K and growth regulators on seed yield and nutrient uptake

Treatments	Days to 50% flowering	Fertility co-efficient%	Seed yield (kg ha^{-1})	Nutrient uptake (kg ha^{-1})		
				N	P	K
A X B interaction						
a_1b_1	62.7	27.67	1114.67	105.51	28.15	47.48
a_1b_2	57.2	25.78	1071.83	111.32	26.72	38.75
a_1b_3	65.5	21.58	934.83	114.75	25.80	36.27
a_2b_1	62.4	25.40	1064.57	106.85	30.78	43.61
a_2b_2	58.5	26.45	1019.70	113.67	27.83	37.57
a_2b_3	66.0	20.69	932.53	107.03	26.12	31.63
a_3b_1	62.7	27.90	1071.83	115.48	29.92	44.58
a_3b_2	57.5	26.70	1034.20	104.34	27.85	36.26
a_3b_3	66.9	22.60	937.13	105.65	25.54	33.50
a_4b_1	61.6	34.11	1186.33	123.30	32.25	52.31
a_4b_2	57.2	31.37	1127.60	120.61	31.45	46.97
a_4b_3	66.9	21.39	930.10	121.40	29.98	40.82
SE m (±)	0.33	0.75	8.68	1.22	0.75	1.66
CD (0.05)	0.999	2.218	25.642	3.610	2.218	2.145
Control-C						
C (RDF alone)	69.1	20.43	916.7	96.78	23.65	29.56
Treatment *vs* control	S	S	S	S	S	S

3.8 Chlorophyll Content

The variations in chlorophyll content with K, growth regulators and their interactions were found to be non- significant. The treatments could not exert any significant influence on the chlorophyll content at flowering. Between the control and treatments also, the chlorophyll content was comparable

3.9 Relative Leaf Water Content
Statistical analysis revealed that the treatments and their interactions did not exert any marked variation in RLWC at flowering. This was in contrast to the reports of Yadhav *et al.* (2019) wherein brassinoids and biofertilizers improved RLWC in vegetable cowpea.

3.10 Soluble Protein Content
Potassium nutrition had significant influence interactions on soluble protein content in leaf at flowering (Table 1) and among the K treatments, a_4 (0.5% KNO_3) recorded the highest soluble protein content (53.64 mg mL^{-1}) on par with a_1, 0.5% K_2SO_4 (52.77 mg mL^{-1}). Soluble proteins act as enzymes that regulate a variety of metabolic activities and are necessary for building cell membranes, pigments and defensive enzymes (Millard, 1988) [18]. The higher soluble protein content in a_4 might be due to the hastened availability of N from foliar applied KNO_3, as N is an important constituent of proteins. The results are in line with Boote *et al.* (2001) [3] in soybean. Further the role of K in amino acid and protein synthesis has been elucidated (Hasanuzzaman *et al*., 2018) [9].
Comparing the effects of the growth regulators (Table 2), the maximum content of soluble protein (57.29 mg mL^{-1}) was noticed in b_1 (GA_3 75 mg kg^{-1}) and was significantly superior to BR 0.1 mg kg^{-1} and HA 100 mg kg^{-1} applications. Kalinich *et al.* (1985) opined that plant growth regulator treated plants show more soluble protein content compared to untreated plants. The increase noticed with GA_3 application might be due to the involvement of gibberellic acid in the transcription and replication process during growth, which increases the enzymes involved in the protein synthesis machinery and hence the protein content (Yu *et al.*, 2004) [36]. The results accord the reports of Wittenbach *et al.* (1980) [34] in soybean and Sumathi *et al.* (2017) [31] in pigeon pea. The treatment combinations, a_4b_1 recorded the significantly superior soluble protein content (60.70 mg mL^{-1}) and the lowest content (43.41 mg mL^{-1}) was recorded in a_2b_3. The significantly higher values in a_4b_1 might be due to the interactive effect of KNO_3 x GA_3 that enhanced the protein content as detailed above which was lacking in the control.
Foliar nutrition with K sources and growth regulators have proven beneficial in pigeon pea as the crop was mobilized to maintain a good source strength through the enhancement of growth with K application and the growth regulators could mobilize translocation of photosynthates in favour of seed yields. The improvement over the control was evident for most of observations studied. This brings to light the need for better management of inputs, including additional doses of N and K along with GA_3 application to realize higher yields in pigeon pea.

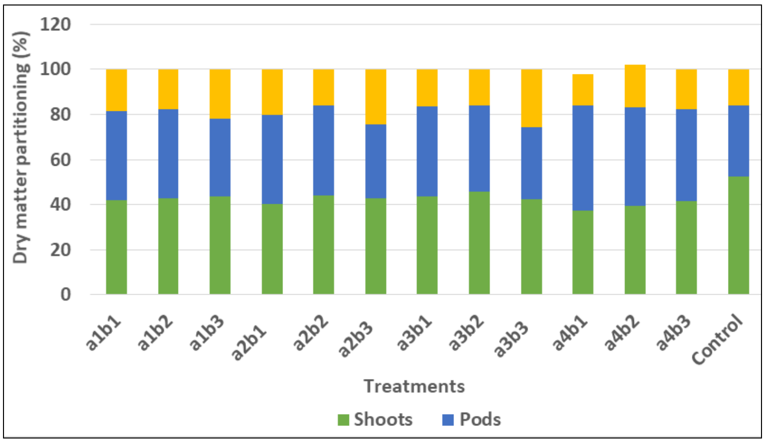

Fig 1: Effect of K x growth regulators on dry matter partitioning in shoots, pods and roots

4. Conclusion
The study elucidates the physiological effects of foliar nutrition in pigeon pea. The application of KNO_3 and GA_3 significantly influenced the vegetative growth, dry matter partitioning, seed yield and nutrient uptake in pigeon pea. Based on the results, foliar nutrition with KNO_3 (0.5%) at flower bud and pod formation stages and GA_3 (75 mg kg^{-1}), 30 DAS and at flower bud stage, can be integrated with the nutrient dose of 40: 80: 40 kg NPK ha^{-1} for enhancing the source- sink balance and hence higher yields in pigeon pea.

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7. Authors' contribution
- **First author:** Execution of the field experiment, data collection, statistical analysis and preparation of manuscript
- **Second author:** Conceptualization, technical guidance, interpretation of results, review as Guide of the first author for his Master's degree and manuscript corrections

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